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**Final Technical Report
DURIP
Grant No: F49620-00-1-0240**

**Title: Integrated Instrumentation System for the Characterization of Polymer Solution and
Gel-Light-Emitting Devices**

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1. Hardware (equipment) summary:

This DURIP grant has contributed strongly in expanding my research activity at UCLA. Being a young professor with limited funding for equipment, this DURIP grant helped me to equip my laboratory and allow me to expand my research activity into different areas, such as the study of nano-scale polymer morphology by using the atomic force microscope. Compared to the originally proposed equipment list, there have been some modifications in the purchased equipment. Our original budget includes a Hewlett-Packard GPC, a Fluorolog 3 spectrometer, an AC impedance meter, a Bio-Analytical Electrochemical Station. However, we later realized that Prof. Fred Wudl, my collaborator on the polymer SLED project, has the HP GPC, AC Impedance meter, and Bio-Analytical Electrochemical Station in his laboratory. He welcomes my group to use those equipments. I consider the best way of using the DURIP funds is to purchase important equipment, and not to duplicate the existing equipment. With the permission from AFOSR (Please see attached document), we used the DURIP funds that we budgeted for the Bio-Analytical station, AC Impedance meter, and GPC to acquire an Atomic Force Microscope (AFM from Digital Instrument Nano-3A) and a Nikon SMZ 1500 Stereo Microscope. The total amount of the purchased equipment is \$194,086. Among them, \$112,063 is from AFOSR's DURIP, and the rest of \$82,023 is matching funds from UCLA and SONY Corporation.

Table 1. List of purchased equipment

Vendor	Equipment	Price
Jobin Yvon Spex	Spectrofluorometer (Fluorog 3)	\$66,763
Nikon	SMZ 1500 Stereo Optical Microscope	\$8,248
Digital Instrument Inc	Nanoscope IIIa Multimode scanning probe microscope (Atomic force microscope) (AFM)	\$119,075
Total		\$194,086
Funds from AFOSR		\$112,063
Matching Funds from UCLA and SONY Corporation		\$82,023

2. Research

Tremendous progresses have been achieved in our research on both solution light-emitting diodes and regular polymer light-emitting diodes. This report only shows experimental results involving the equipment listed in Table 1.

Physical modeling of solution light-emitting diodes

Our previous report presented a new type of polymer light-emitting devices – polymer solution light-emitting diodes (SLEDs) [1] invented by our group. In addition, I-V characteristics and transient properties of SLEDs have also been presented in the 2000 AFOSR-DURIP proposal. The current report focus on the mechanism and the physical modeling of the SLEDs.

AC impedance measurement (*done by HP AC Impedance Meter 4284A*) associated with cyclo-voltalmetry (*CV, done by Bio-Analytical Systems MF100BW-100000*) characterization have proved that the mechanism of SLEDs with a structure of ITO/polymer solution/ITO is an electrogenerated chemiluminescence (ECL) process [2,3]. The experimental results also suggest that the SLEDs can be described by equivalent circuits (Figure 1), consisting of a device capacitance (C_1), a solution layer resistance (R_1), an interface capacitance (C_2) and an interface resistance (R_2) between the ITO electrode and the solution layer. Furthermore the dependence of impedance behaviors of SLEDs on the amplitude of bias suggests that probably more than one mechanism are involved. When the voltage is at the medium range, i.e. higher than the difference between the oxidation potential (a process that produce radical cations) and the reduction potential (a process that produce the radical anions) but still lower than a critical voltage (8V according to our initial results), impedance results indicate that the SLEDs are controlled by the ECL process. However, further increase the voltage beyond 8V leads to impedance behaviors similar to that of the polymer light-emitting cells (LECs) rather than ECL. This observation indicates that the mechanism of SLEDs operated at a voltage beyond the critical voltage might involve the direct charge injection into the conjugated polymer, transport (hopping) along/within the polymer chains, and then radiative recombination of those injected charges.

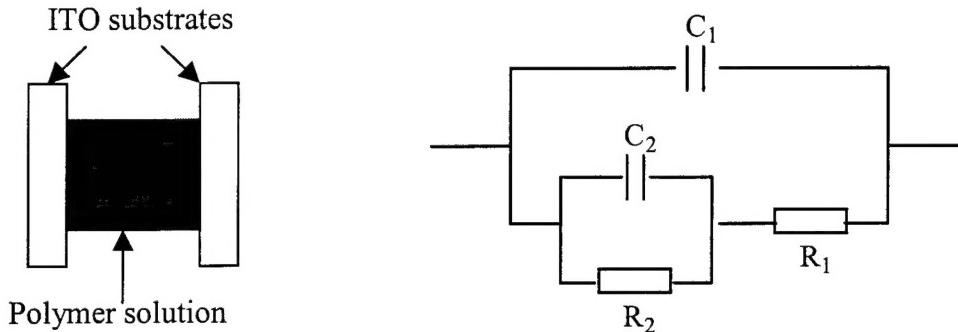


Figure 1. Typical structure of SLEDs (left) and the equivalent circuit (right)

Effects of polymer morphology on device performance

PLEDs have an advantage of easy and low-cost fabrication due to the solution processibility of conjugated polymers. In the past decade, numerous efforts have been focused on the device study and material design, *etc.* It was not until recently, polymer morphology has been realized to play a role of influencing the physical properties of polymer LED.

It has been recently found that the morphology of MEH-PPV^a plays an important role in influencing the optical and electrical properties of polymer films and PLEDs, such as the photoluminescence (PL) spectrum, the electroluminescence spectrum, the polymer/metal contacts, the turn-on voltage and the quantum efficiency etc [4,5,6]. Furthermore, the polymer morphologies as well as the device performances have been correlated to the fabrication parameters, such as the conditions of spin coating and thermal annealing [7]. Figure 2 shows an example of how the annealing temperature influences the PL spectra of MEH-PPV polymer films.

Tailoring the polymer morphology and optimizing the conditions of fabrication have dramatically improved the device performances. In addition, the device performances have been further improved by constructing devices with new structures, such as using polymer solid solutions [8] rather than homogeneous polymers along. Figure 3 shows an example of improving device efficiency by forming MEH-PPV/PF^b solid solutions. As can be seen from Figure 3, at an injection current of 3mA, the efficiency of the 4% MEH-PPV/PF device (3.9cd/A) is 70% higher than that of the pure MEH-PPV device (2.2 cd/A). The studies of PL excitation spectra characterized by *Spex spectrofluorometer* and surface morphologies

^a MEH-PPV stands for poly(2-methoxy-5-(2'-ethyl-hexyloxy)-1,4-phenylene vinylene

^b PF refers to poly(9,9-diethylfluorene).

characterized by *Atomic Force Microscope (AFM, Digital Instrument Nano-3a)* is shown in Figure 4. These two sets of figures suggested that improved device performances mainly benefit from suppressed interchain interactions (aggregates), and forming nano-scale of hetero-junctions between the host polymer and the MEH-PPV. In addition to regular PLED, we also intend to fabricate micron size polymer LED at different locations of polymer thin film such that we can further characterize the physical properties of polymer thin films. The Nikon SMZ 1500 stereo microscope will be used to control the micro-contacts to these micron-size PLEDs.

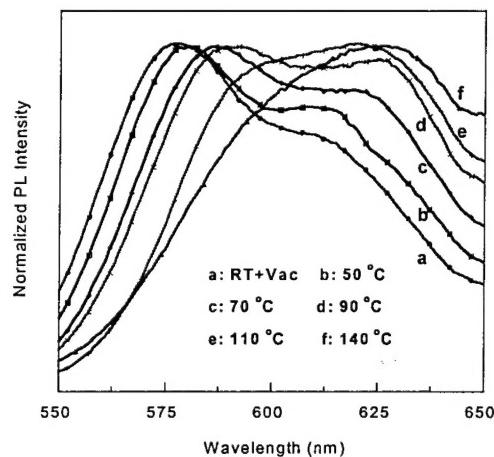


Figure 2. Normalized photoluminescence spectra of MEH-PPV films annealed under different conditions

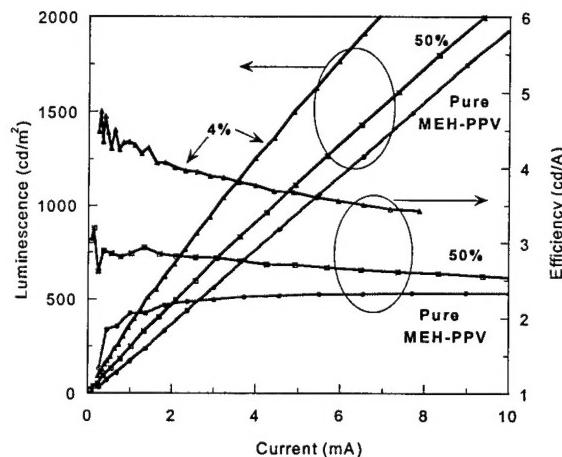


Figure 3. Luminescence - current - efficiency curves of devices of the pure MEH-PPV, 4% and 50% MEH-PPV/PF solid solutions

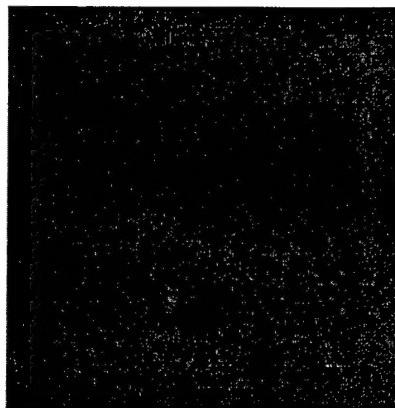


Figure 4. AFM phase-images of (left) 17% and (right) 4% MEH-PPV/PF solid solutions. Both scans are $3 \mu\text{m} \times 3 \mu\text{m}$. The contrast covers phase angle variation in the 50° range.

New methods of fabricating polymer films and PLEDs

Several different methods, such as lamination [9] and bar-coating [10], have been developed to fabricate polymer thin films and PLEDs. Those equipments purchased with the

DURIP program have been intensively used to characterize the properties of polymer films fabricated by those methods. Figure 5 shows an example of the fluorescence polarization properties of MEH-PPV films fabricated with the spin coating and the bar-coating technique, respectively. Spin coated MEH-PPV films have a weak but still detectable fluorescence polarization (characterized with *Spex spectrofluorometer*) because of the asserted external force – centrifugal force during the spin-coating, which also cause the non-uniformity of polymer films due to the location dependence of the centrifugal force. However, bar-coated MEH-PPV films show a much smaller polarization because of the absence of or if any, much weaker, external force and the films are much more uniform.

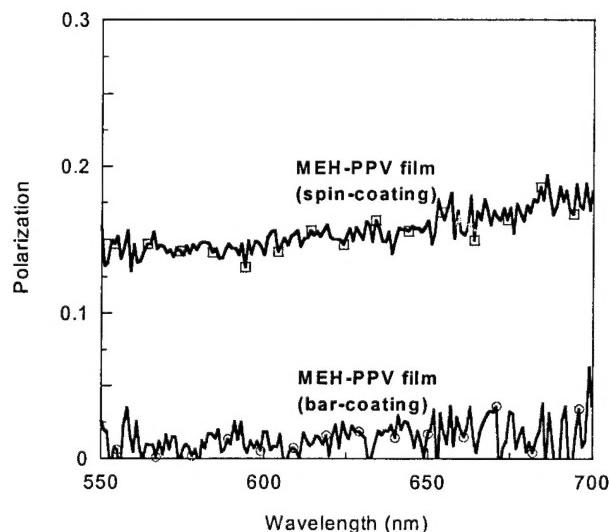


Figure 5. Fluorescence polarization of MEH-PPV films fabricated with the spin-coating and bar-coating techniques

3. Education

The equipment purchased with DURIP program also helps the training of our graduate students. In addition, experimental demonstrations were also given to undergraduates in the course MSE 150 “*Introduction to Polymer*” and graduate students in the course MSE 298 “*Organic Functional Materials*” with an aim of helping them gain the fundamental principles of those equipment and their basic applications in organic/polymer characterizations. In those classes, the AFM was used to show the polymer surface morphology and the *Spex spectrofluorometer* was demonstrated to study the optical properties of conjugated polymer.

Reference

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Date: Tue, 13 Jun 2000 17:28:23 +0000
From: Sharma Bhawana Civ AFRL/AFOSR <bhawana.sharma@afosr.af.mil>
Subject: F49620-00-1-0240, Reallocation of funds
To: "yangy@ucla.edu" <yangy@ucla.edu>
X-Mailer: Internet Mail Service (5.5.2607.0) iy 4

SUBJECT: University of California, Los Angeles
F49620-00-1-0240, Reallocation of funds

Reference grantee's letter dated 06 Jun 00, requesting permission to reallocate funds within the DURIP grant to substitute equipment in lieu of what was originally proposed. The subject grant has the "Federal Demonstration Partnership III, dated 1 July 1997 and AFOSR Agency Specific Requirements, October 1999 incorporated by reference. Prior approval for the requested change is not necessary under the terms covered in the brochure. Linda White, (310) 794-0165 was notified on 13 Jun 00 of this. No further action was taken. Grantee understands that change in equipment shall NOT result in increased cost to AFOSR.

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